Investigation on Non-volatile and Non-rotation Phase Change Random Access Memory

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Abstract

Phase Change Random Access Memory (PCRAM), also known as Ovonic Unified Memory (OUM) is based on electric induced thermal phase-change between the amorphous and crystalline states in a phase change thin film. This paper will report on our research on development of PCRAM, including materials research, design software development, simulation, IC design, fabrication, testing and tester development.

In this work, many phase change materials were deposited and their material properties have been measured including resistance, crystallization temperature, melting point, density, band gap and activation energy. A software for PCRAM design was developed. This software was developed on multidisciplinary theories including electrodynamics, thermal conduction, crystallization kinetics and numerical computations. Various types of PCRAM cells can be designed. This software provides powerful PCRAM cell design functions including cell geometry, multiple layer structures, set and reset processes with different electrical pulses. Based on Poisson's equation, the electric potential, electric field, electric current density can be simulated; based on Fourier thermal conduction, the temperature field can be solved; based on crystallization kinetics, the switching process from high- to low-resistance phase can be evaluated. We use finite element method (FEM) and grid computation technique to solve the thermal-electric coupled process. Thus, this software can carry out electric and thermal analysis of the designed PCRAM cell including electric potential, electric field, and electric current density, temperature distribution, heating and cooling processes and active area generation. It provides an integrated analysis function. The software also has a user-friendly interface, data base of material properties and strong visualization functions.

The thermal and mechanical performances, such as temperature distribution and thermal expansion, and the determination of the influence of cell structure, electrical peak power, pulse length and recording speed, and the cell layer structures on performance were investigated by simulation.

According to the classic crystallization theory, crystallization from amorphous involves two distinct processes, i.e., the nucleation of small crystallites and the subsequent growth. Based on the characteristics of nucleation and growth phenomena phase change material can be identified as the nucleation-dominated or the growth-dominated materials. They have been found that the recoding behavior on optical recording disks is quite difference. The complete erasing time (CET) of a growth-dominated material increased with increasing the mark size while the CET of a nucleation-dominated material increased slightly as the size of written marks increased. In this work, the difference between nucleation-dominated and growth-dominated phase change materials applied in PCRAM was studied theoretically and experimentally.

PCRAM array was designed, fabricated, and tested by using a self built tester. Near-field optical scan microscope incorporated with fs laser was used to fabricate nano-scale PCRAM cells. In this work, a superlattice like (SLL) structure was applied to PCRAM. This SLL phase change structure incorporates two non-promising phase change materials. One has high phase change speed but poor stability, whereas the other has good stability but low phase change speed. Neither of them could meet the requirement of PCRAM when used alone. A properly designed SLL structure could balance both of phase change speed and stability. In this work, the PCRAM with SLL structure exhibited reduced resetting and setting current. The fastest working speed of 5ns was observed for both resetting and setting. A methodology was developed to evaluate the retention of the SLL structure. It showed that the retention of the SLL structure is more than 10^7. The performance of SLL PCRAM was found related to the configuration of SLL phase change stack, such as individual layer composition and thicknesses, layer number and sequence.